EFFECT OF RADIUS OF FILLET ON SHEAR STRESS FOR CYLINDRICAL SHAFT

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ABSTRACT

This project presents an investigation effect of the radius of the fillet on shear stress for cylindrical shaft by using finite element analysis. The shaft has the tendency to fail due to the inappropriate design of fillet radius. Hence, the best models need to design. 18 models were constructed with different ratio two diameters shaft and radius of fillet in SOLIDWORK. These models imported into PATRAN software to analyze the models with different given of the value of torque. In order to simulate torque, MPC RBAR was employed on model. AISI 4130 was selected material for all models. The value for Young Modulus of Elasticity = 206GPa and the Poisson Ratio = 0.3 was used in this analysis. The stress concentration factor was determined to compare the simulation result and equation. As expected, result showed that increased the radius of fillet of shaft reduced the value of shear stress. The ratio of two diameters shaft 1.09 was the best design compared to others because all cases produced the lowest value of shear stress. The value of shear stress was increase when the torque given was increased.

ABSTRAK

Projek ini mempersembahkan mengenai kesan penyiasatan jejari kambi pada tegasan ricih untuk aci silinder dengan menggunakan analisis unsur terhingga. Aci mempunyai kecenderungan untuk gagal kerana reka bentuk yang tidak sesuai jejari kambi. Oleh yang demikian, model yang baik perlu di reka. 18 model telah dibina dengan nisbah yang berbeza dua diameter aci dan jejari kambi dalam SOLIDWORK. Kemudian, model-model yang diimport ke dalam perisian PATRAN penganalisis model dengan yang berlainan diberi nilai tork. Supaya dapat merangsangkan tork, MPC RBAR telah bekerja pada model. AISI 4130 telah dipilih bahan untuk model semua. Nilai Modulus Young = 206GPa Keanjalan dan Nisbah Poisson = 0.3 telah digunakan dalam analisis ini. Faktor tekanan kepekatan telah ditentukan untuk membandingkan hasil simulasi dan persamaan. Seperti yang dijangka, hasil menunjukkan bahawa meningkat jejari kambi aci mengurangkan nilai tegasan ricih. Nisbah dua diameter aci 1,09 adalah reka bentuk yang terbaik berbanding dengan yang lain kerana semua kes-kes yang menghasilkan nilai terendah tegasan ricih. Nilai tegasan ricih adalah meningkat apabila tork yang diberikan telah meningkat.

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LIST OF SYMBOLS

τ	Shear stress
G	Modulus of rigidity
γ	Shearing strain
ρ	Shearing stress in the shaft varies linearly with the distance
c	Circle of radius
J	Polar moment of inertia
T	Torque
K	Stress concentration factor
τ_{max}	Maximum shear stress
r	Radius of fillet
D	The largest diameter of shaft
d	The smallest diameters of shaft

LIST OF ABBREVIATIONS

CAD	Computer-aided drafting
CAE	Computer-aided engineering
DOF	Degree-of-freedom
UMP	University Malaysia Pahang
FEA	Finite element analysis
FEM	Finite element method
SAE	Society of Automotive Engineers

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

A shaft is the component of a mechanical device that transmits rotational motion and power. It is integral to any mechanical system in which power is transmitted from a prime mover, such as an electric motor or an engine, to other rotating parts of the system. There are many examples of mechanical systems incorporating rotating elements that transmit power: gear-type speed reducers, belt or chain drives, conveyors, pumps, fans, agitators, household appliances, lawn maintenance equipment, and parts of a car, power tools, machines around an office or workplace and many types of automation equipment. Torsional , bending and normal forces occur during the working of the shaft (Heisler, H. 1999). The forces cause a combination of normal and shear stresses which applied cyclically on the shaft.

The stress concentrations can be determined in a shaft by various method : mathematical methods, photoelasticity, Finite Element Method and others. There are researcher determine stress by using finite element method such as Bayrakceken, H. (2007) analyzed fatigue failure of driveshaft and universal joint yoke by the finite element method and Taylor, D. et al. (2011) also use finite element method to study about two new methods for reducing the stress concentration features .

The geometry of a shoulder fillet has long been of interest to shaft designers and structural analysts. FEA was used to analyze additional fillet shaft geometries. Shouldered shafts with conical tapered sections tangent to a fillet radius were studied by Jallipalli. et al. (1997). Then the more general case of a shoulder with a tapered section that is not necessarily tangent to the fillet was study by Schmidt. et al. (2006).

In this project, the stress analysis of shaft was carried out by using finite element analysis. The different design of various steel shafts was created by using SOLIDWORK to determine the value of shear stress with variable torque. This study to prove that stress can be reduced through the use of a fillet.

1.2 PROBLEM STATEMENT

A shaft is the component of a mechanical device that transmits rotational motion and power, usually of circular cross section either solid or hollow. There are different designs of shaft which can classify fillets into two categories namely sharp and well rounded, when a change in diameter occurs in a shaft to create a shoulder against which to locate a machine element, a stress concentration dependent on the ratio of the two diameters and on the radius in fillet is produced. Besides that, the shaft has the tendency to fail due to the inappropriate of fillet radius. Hence, there is need to construct model with the best design which is consider to the value of stress concentration, K so that the value shear stress will be decrease. Therefore, the main objective of this project is to examine stress analysis which to determine the shear stress for cylindrical shaft with various values of fillet by using FEA. The research work is focus on fillet in order to approve the stress can be reduced through the use fillet.

1.3 OBJECTIVE

The objective of this project:

a) To investigate effect of radius of fillet on shear stress for cylindrical shaft with various values of fillet by using finite element analysis.

b) To compare shear stress the value of shearing stress with the different the ratio of the two diameters.

1.4 SCOPE OF THE PROJECT

The scopes of this project as below are determined in order to achieve the objectives of the project:

a) Construct the model of cylindrical shaft with different of the ratio of the fillet to the diameter shaft and the ratio two diameters of shaft by using SOLIDWORK.

b) Determine the value of stress concentration, *K*

c) Analysis the shear stress with different model to prove that shear stress can be reduced through the fillet by using MSc PATRAN software.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter will explain more about the information collected related study on effect radius of fillet on shear stress for cylindrical shaft and provide additional information and relevant fact. It cover are of interested subtopic such as torsion of shaft, stress concentration factor, K, application of shaft, finite element analysis, and material of shaft.

2.2 Torsion of shaft

Torsion occurs when any shaft is subjected to a torque. The torque makes the shaft twist and one end rotates relatives to the other inducing shear stress on any cross section.

2.2.1 Stress in the elastic range

From the Hooke's Law for shearing stress and strain.

$$\tau = G\gamma \qquad (2.1)$$

Where G is the modulus of rigidity or shear modulus of the material. The shearing strain,γ at a distance ρ from the axis of the shaft as :

$$\gamma = \frac{\rho}{c}\, \gamma_{max} \qquad (2.2)$$

Multiplying Eq 2.2 by G,

$$G\gamma = \frac{\rho}{c}\, G\, \gamma_{max} \qquad (2.3)$$

$$\tau = \frac{\rho}{c}\, \tau_{max} \qquad (2.4)$$

The equation obtained shows that, as long as the yield strength is not exceed in any part of circular shaft, the shearing stress in the shaft varies linearly with the distance, ρ from the axis of the shaft.

The sum of the moments of the elementary force exerted on any cross section of the shaft must be equal to the magnitude T of the torque exerted on the shaft.(Ferdinand P.Beer. et al. 2009)

$$\int \rho\ (\tau\, dA) = T \qquad (2.5)$$

Substituting for τ from (2.4) in to (2.5) :

$$T = \int \rho\tau\ dA = \frac{\tau_{max}}{c} \int \rho^2\ dA \qquad (2.6)$$

Where J is polar moment inertia of circle of radius, c is

$$J = \frac{1}{2}\, \pi c^4 \qquad \text{(for solid shaft)} \qquad (2.7)$$

So, the elastic torsion formula as :

$$\tau_{max} = \frac{Tc}{J} \qquad (2.8)$$

Where ;

T = torque, (N.m)
c = circle of radius, (m)
J = polar moment of inertia, (m^4)
τ = shear stress, (N / m^2)

2.2.2 Stress concentration factor, *K*

In the case of shaft with a change in the diameter of its cross section, however, stress concentrations will occur near the discontinuity, with the highest stresses occurring at the fillet of shaft. These stresses may reduced through the use of fillet and the maximum value of the shearing stress at the fillet can be expressed as

$$\tau_{max} = K\,\frac{Tc}{J} \qquad (2.9)$$

The factor of *K* depends only upon the ratio of the two diameters and the ratio of the radius of the fillet to the diameter of the smaller shaft. The geometry of a shoulder fillet has long been of interested to shaft designers and structural analyst. For years engineers relied on solutions estimated by (Pilkey, W.D. et al. 2008) as presented in Figure 2.1 in the form of graphical design charts. Figure 2.1 was used to help determine the *K* value of a shoulder fillet on a cylindrical shaft in bending, torsion and tension.

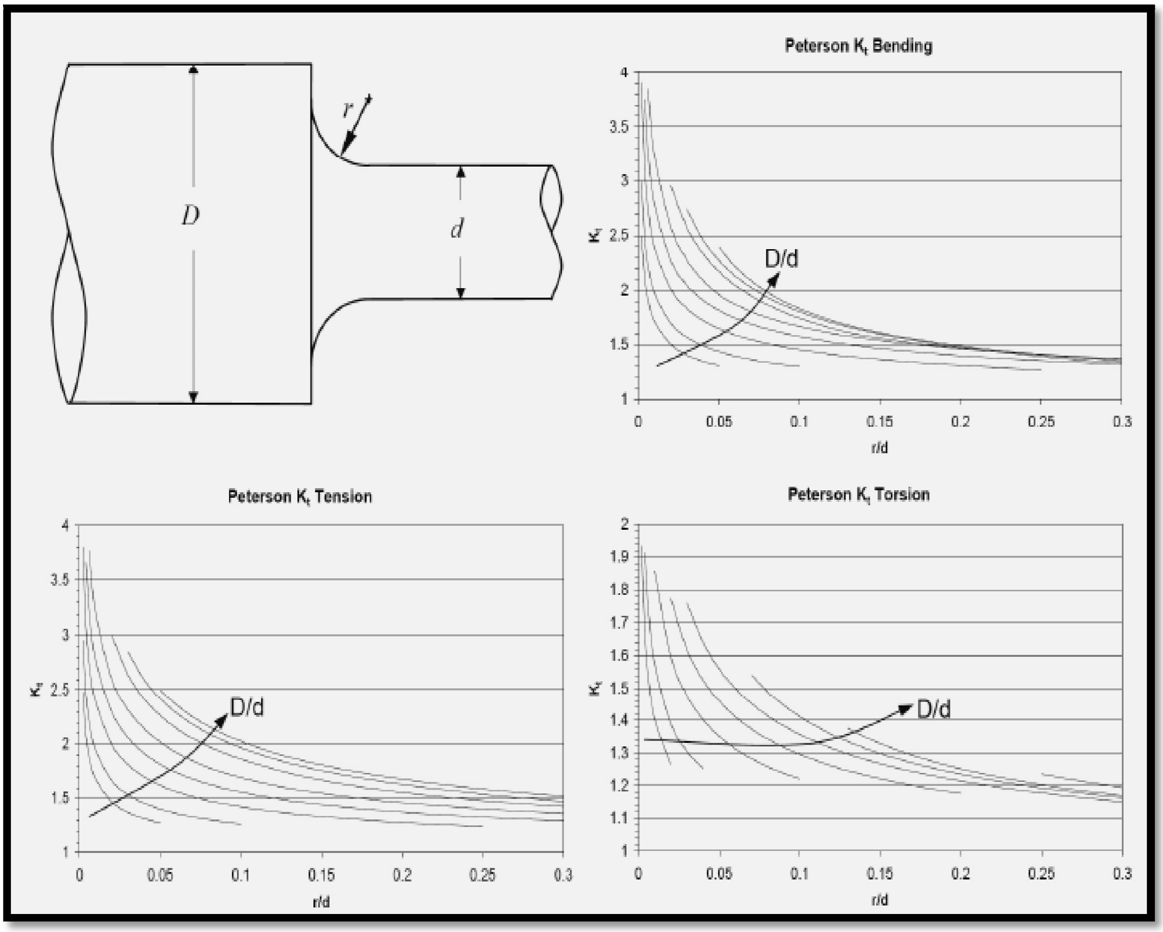

Figure 2.1 : Stepped shaft Geometry and Peterson original solutions for bending, tension and torsion

Sources : (Pilkey, W.D. et al. 2008)

Goksenli, A. et al. (2009) study about the failure analysis of an elevator drive shaft. This research found that the when the radius of curvature increase will reduce the shear stress. Figure 2.2 show the result of effect of radius of curvature on stress distribution.

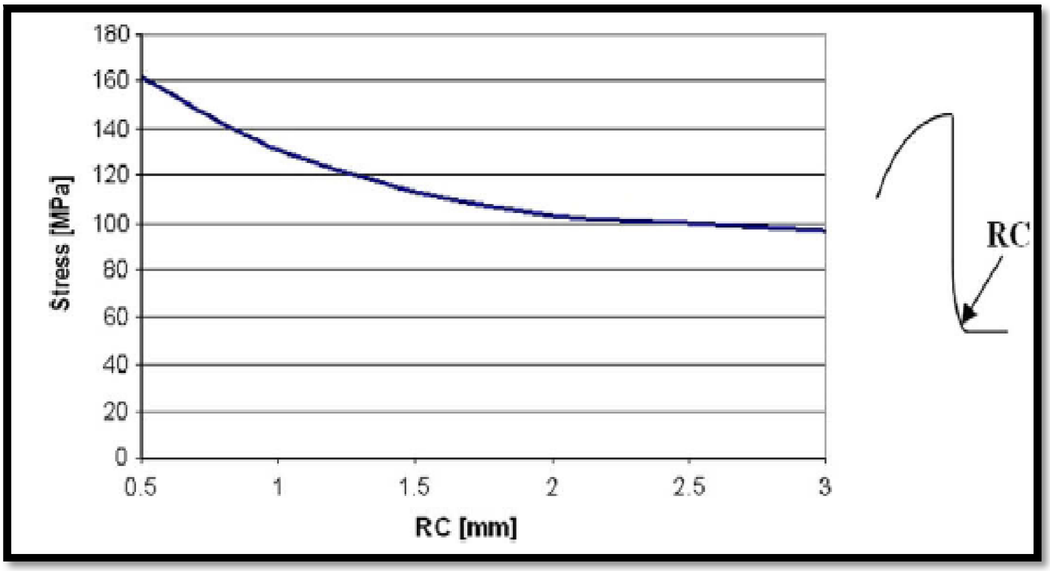

Figure 2.2 : Effect of RC on stress distribution

Source : Goksenli, A. et al. (2009)

2.3 APPLICATION OF SHAFT

There are many examples of mechanical systems incorporating rotating elements that transmit power: gear-type speed reducers, belt or chain drives, conveyors, pumps, fans, agitators, household appliances, lawn maintenance equipment, and parts of a car, power tools, machines around an office or workplace and many types of automation equipment

2.3.1 Drive Shaft

The torque that is produced from the engine and transmission must be transferred to the rear wheels to push the vehicle forward and reverse. The drive shaft must provide a smooth, uninterrupted flow of power to the axles. The driveshaft and differential are used to transfer this torque. Figure 2.3 showed the vehicle drive train which is showed the driveshaft is the connection between the transmission and the rear axle of the car.

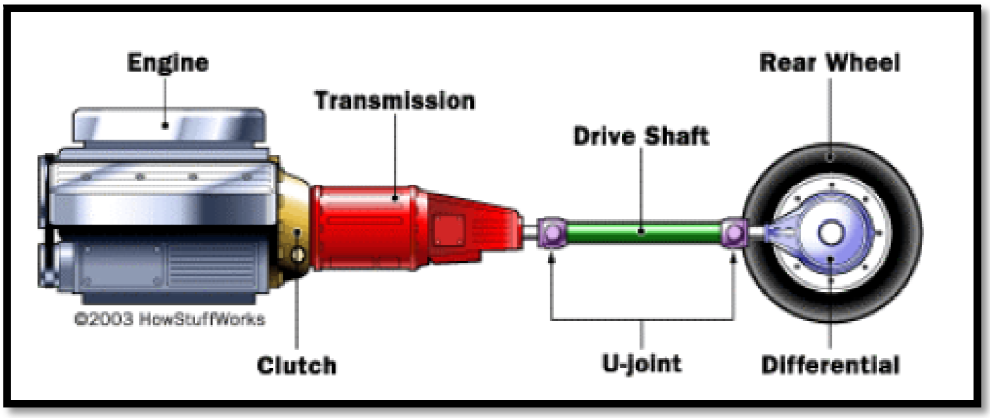

Figure 2.3 : Vehicle drive train

Source : Chad, K. et al. (2004)

2.3.2 Elevator Drive shaft

Goksenli, A. et al. (2009) study failure analysis of an elevator drive shaft. Elevator drive system is mounted at the bottom of building in Figure 2.4. Torque which is produced by an electric motor is transmitted by a worm gear to shaft. The shaft rotates the pulley by a key.

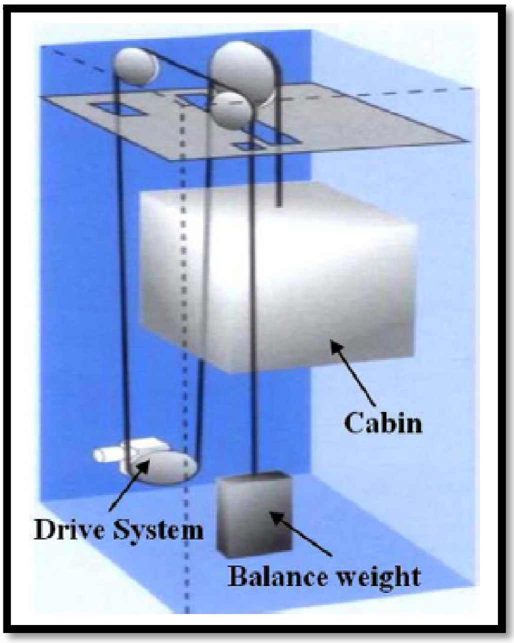

Figure 2.4 : Elevator system inside building

Source : Goksenli, A. et al. (2009)

Figure 2.5 showed the elevator drive system which is the shaft is supported in three points in form of journal bearings.

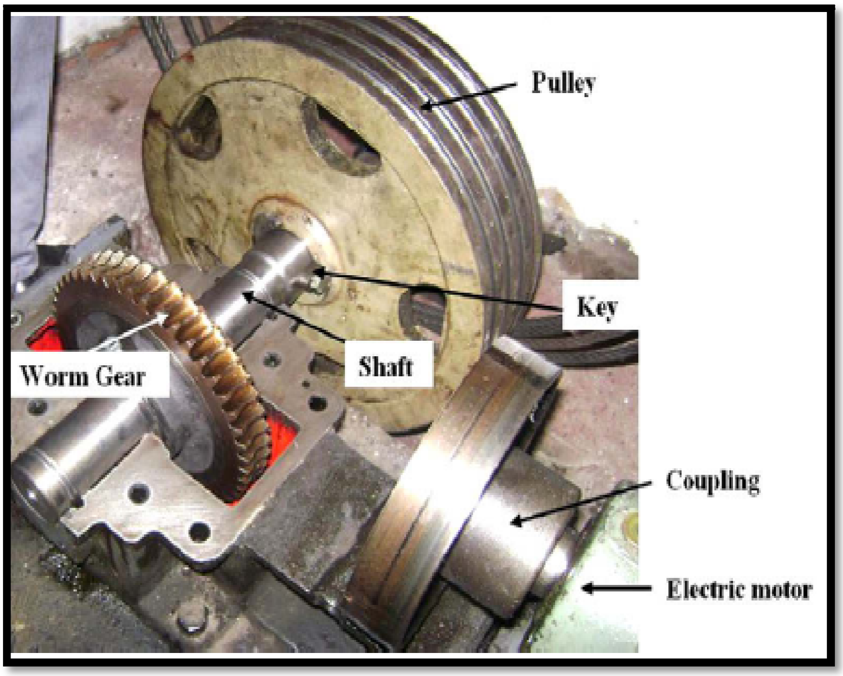

Figure 2.5 : Elevator drive system

Source : Goksenli, A. et al. (2009)

2.3.3 Turbine Engine Shaft

A turbine engine shaft transfer torque created by the engine's the turbine to the engine's compressor. In this process, the turbine shaft incurs rotational shear loads, bending loads, and a thermal gradient. Figure 2.6 shows the turbine engine.

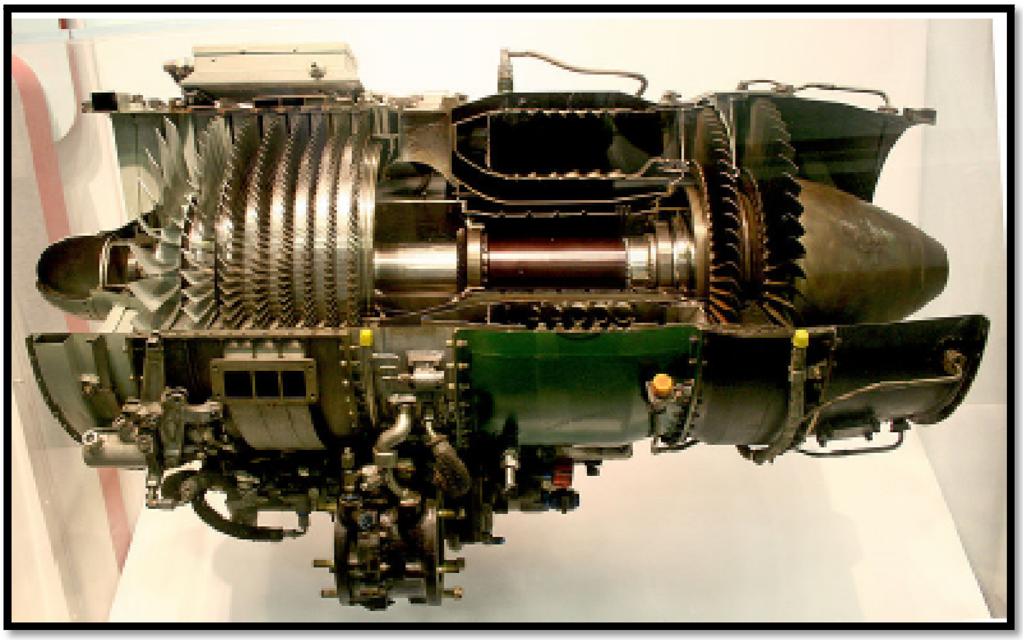

Figure 2.6 : A GE J85 turbine engine cut away so internal are visible. The shaft can be clearly seen.

Source : Steven Dallas Townes Jr. (2009)

2.4 FINITE ELEMENT ANALYSIS

Most recently, advance in technology have produced computers that are capable of quickly and efficiently running simulated analyses of geometrically complex components. The finite element method (FEM) has been established for many shaft as a means of analytically determining stresses but its usage has been somewhat limited by the processing power available. Goksenli, A. et al. (2009) showed that it was possible to accurately analyses an elevator drive shaft with the FE method. Their investigation was carried out with 3D model. A precise geometrical model of the shaft was built up and then imported to ANSYS to analyse the stress occurring at the keyway corner. Figure 2.7 shows the finite element mesh of the shaft.

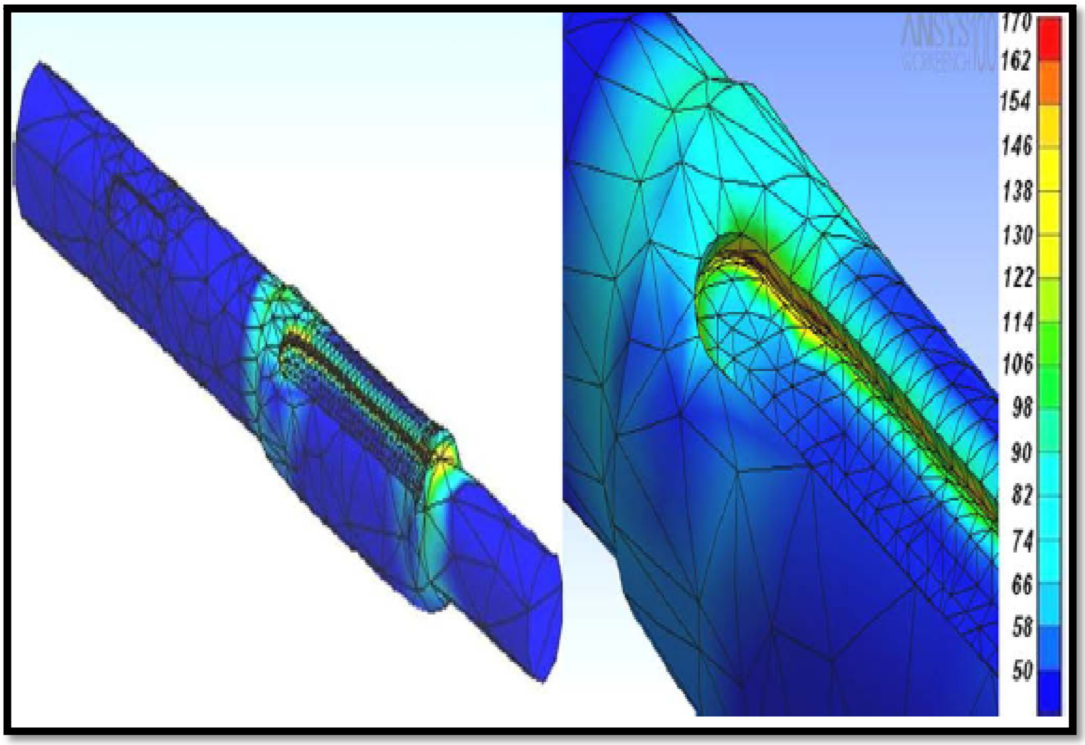

Figure 2.7 : Finite element mesh of the shaft

Source : Goksenli, A. et al. (2009)

Bayrakceken, H. (2007) research about two cases of failure in the power transmission system in vehicle. Finite element analysis technique is used to determine the stress distribution at the failed section and to obtain the best design. After the construction of the geometric model, a static stress analysis is carried out by entering the obtained mechanical properties of the material (Elastic Modulus = 205GPa, Poisson Ratio = 0.29). The load are lateral bending load of weight of the full car (2500N) and torsional moment for turning of the wheel 100N.m. The mesh consist of 11,486elements and 20,612 nodes. Boundary condition are applied at the bearing and geared coupling locations. Figure 2.8 show that the highest stress occur at the fillet region of the failed cross section.